The Trilogy update of IEEE C62.41

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Significance:
Part 2 – Development of Standards – Reality checks
Part 6 – Tutorial reviews

A progress report on the development of the Trilogy, presented in a forum organized by the lightning protection community, to promote harmonization of standards.

It is ironic that in early-2000, when this paper was written, the working group expectation was that by mid summer a satisfactory consensus would be reached. Alas! The reality is that it took two recirculations to achieve such a consensus, to the point that publication of the Trilogy could not be accomplished before early 2003, almost three years after this paper was written.

ICLP 2000
Rhodes - Greece
18-22 September 2000

THE TRILOGY UPDATE OF IEEE Std C62.41

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Abstract: Progress report on the restructuring of two IEEE standards concerned with surges in low-voltage a.c. power circuits into a Trilogy of three documents. First a basic Guide describes the surge environment, then a Recommended Practice proposes a limited set of representative surge waveforms for test purposes, and finally a Recommended Practice shows how to perform safe, repeatable and reliable surge tests on equipment connected to these a.c. power circuits.

Key Words: lightning, surges, standards

1. INTRODUCTION

Since 1980 when the seminal IEEE Std 587 *Guide on Surge Voltages in Low-Voltage AC Power Circuits* was first approved, the document has gone through several revisions, while a companion, IEEE Std C62.45 *Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits* was developed to provide guidance on test procedures. Experience in applying the documents, and the availability of new information on the subject led to a decision of performing a major update of the two documents, mostly the C62.41. The purpose of this paper is to present a progress report on the project and invite the International Conference on Lightning Protection (ICLP) community in sharing common interests about the occurrence of surges in low-voltage a.c. power circuits.

2. HISTORY

In 1991, the 1980 version of the IEEE 587 Guide (which had been renamed IEEE/ANSI C62.41 soon after its original issue) was upgraded to a Recommended Practice, with the addition of new recordings to the data base, and the definition of "Additional Test Waves" to the seminal 100 kHz Ring Wave and Combination Wave (1,2/50 - 8/20 μs).

Since 1991, the Recommended Practice remained unchanged, but new information for the data base, and the perception of a need to describe the scenario of a direct flash to the building - not included in the scope of the 1980-1991 versions - have created a situation where a mere update of the document would be insufficient.

Consequently, the IEEE Surge Protective Devices Committee and the Standards Board of the IEEE have approved a new project, now known as "The Trilogy" whereby the two documents, C62.41 [1] and C62.45 [2], will be replaced by three separate, but related (and published simultaneously) IEEE standards. The present C62.41-1991 will be split in two, C62.41.1 and C62.41.2, while C62.45 will remain separate but better connected to the two C62.41 documents.

3. THE TRILOGY

The identification of the three documents will be:

- C62.41.1-2000 - IEEE Guide on the Surge Environment in Low-Voltage AC Power Circuits
- C62.41.2-2000 - IEEE Recommended Practice on Characterization of Surges in Low-Voltage AC Power Circuits
- C62.45-2000 — IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits

To place these three documents of the Trilogy in perspective, note that the IEEE generically refers to three types of documents as "standards":

Guides, in which information is presented with no attempt to steer the reader in a unique direction;

Recommended Practices, in which several possible choices are presented, and one is recommended as the first choice;

Standards, in which a single approach is specified, with no deviation allowed.

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The last document of the Trilogy, C62.45 will not have major changes. It will be an update to make it consistent with the recommendations of C62.41.2, with the addition of some practical tips on how to perform more reliable surge measurements. In contrast, the first document of the 1990s vintage, C62.41, is undergoing major restructuring. The purpose and the contents of these three standards are summarized in the three following Sections 4, 5, and 6.

4. GUIDE ON THE SURGE ENVIRONMENT

4.1 Data base

The initial approach to a description of the surge environment was limited to compiling the results of surge measurements made in the field, either by systematic monitoring, or on the occasion of staged tests, generally in connection with equipment failure investigations. As the development progressed, it was recognized that additional information on the surge environment can be gained by incorporating other data. In its new structure as a Guide four elements will be included into the data base:

1. Recordings of surge events in the field;
2. Numerical simulations and laboratory research;
3. Inferences on the surge environment drawn from analysis of equipment field failures;
4. Discussion of the data base.

The 1980 and 1991 versions of C62.41 proposed the concept of "Location Categories" as follows, in an effort to guide designers and users of equipment toward a realistic perception of the surge threat depending on the general location within a building, but not precise distances.

4.2 Location Categories

The concept of Location Categories was based on the fact that the inherent inductance of the building wiring would reduce the ***current*** stress imposed by an impinging surge as distance from the service entrance increases, while the ***voltage*** stress would not be affected. The concept was illustrated in graphic form, showing buildings where increasing distance from the service entrance were marked by fine-line demarcations between the categories. Of course, electrons flowing in the wiring were blissfully unaware of these demarcations, a fact that was troublesome to some readers of the document. A possible misinterpretation of these fine-line demarcations might have implications on the rating specifications of surge-protective devices (SPDs) to be installed at a specific location.

To avoid this too-narrow interpretation the updated Guide will emphasize that "boundaries" ***separating*** the categories should rather be seen as "transitions" ***connecting*** the categories that overlap. The graphic illustration of the three Location Categories A, B, and C will show, rather than the fine lines of 1991, the amended concept and representation with transition overlaps, as seen in Figure 1.

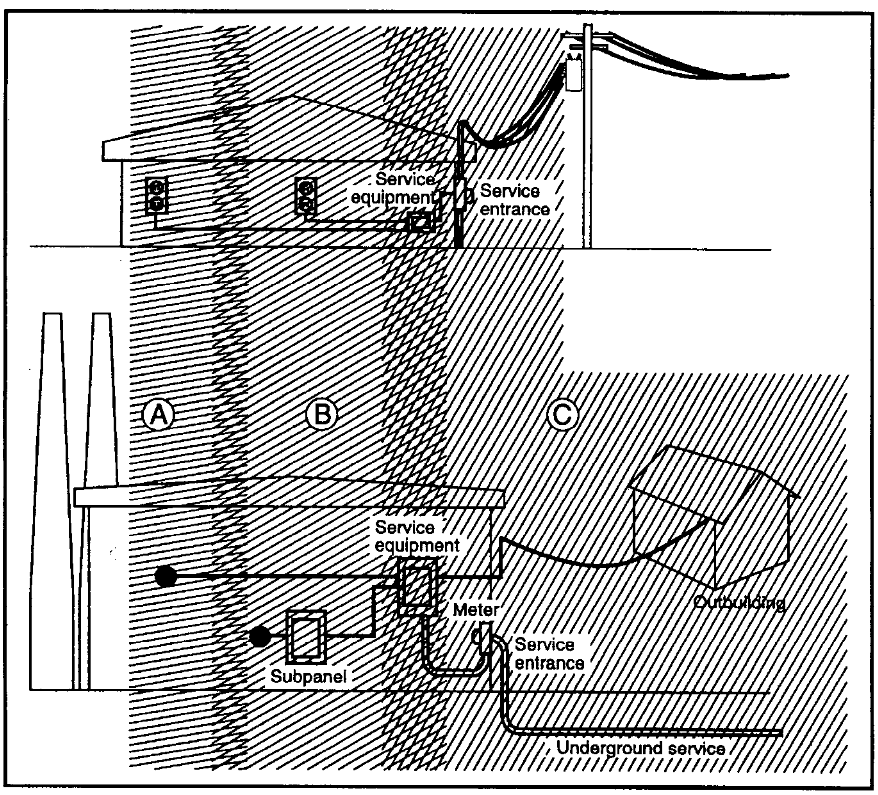


Figure 1 — The concept of Location Categories connected by transition overlaps

4.3 The tale of two scenarios

However, the concept of Location Categories was and remains implicitly applicable only for surges impinging upon the building from the outside or generated within. These were considered to be the vast majority of surge events, and the more rare event of a direct flash to the building was considered a special case, which was not addressed in the document. The updated version will now include that situation, as described in Section 5.

Given the increasing interest, and some of the undocumented perceptions on what is involved in the scenario of a direct flash to a building, the Trilogy is attempting to provide information presented in a manner that will be useful and realistic. To emphasize the major difference between common surge events and a less frequent direct flash, the surge environment description of C62.41.1 is presented in two separate scenarios:

- Scenario I: All surges impinging from the outside or generated within the building, except for Scenario II
- Scenario II: Surges resulting exclusively from the dispersion of the lightning current in the earthing electrodes

The concept of presenting the two scenarios has been well accepted among the members of the IEEE Surge-Protective Devices Committee. One of the pitfalls in applying this scenario might be an oversimplification made in a well-intentioned attempt to simplify the complexity of the dispersion of the lightning current among the available paths to multiple earthing electrodes. Figure 2 shows an already very simplified building wiring with extraneous metal which still suggests multiple paths for the dispersion.

So far, few if any ***measurements*** have been reported in the literature to document the details of the dispersion of lightning current within a building [3]; [4]. However, several numerical ***simulation*** studies have been conducted [5]; [6]; [7], all involving a certain degree of simplification [8]. This evolving situation is closely monitored by the IEEE working group where the Trilogy is being developed, to provide the latest consensus at the time of balloting, but realizing that this consensus is an ever-evolving goal.

4.4 From data base to representative waveforms

In turn, the environment description of the C62.41.1 Guide will serve as the basis for the definition of the waveforms given in the C62.41.2 Recommended Practice, as described in the next section. The waveforms that were proposed in the 1991 version will be maintained in the description of Scenario I, but the definition of appropriate parameters for Scenario II is still unresolved as of the writing of this paper. Consensus might be reached among interested parties by the time of oral presentation of this paper at the ICLP Rhodos, where the most recent results of this process can be reported.

5. RECOMMENDED PRACTICE ON CHARACTERIZATION OF SURGES

5.1 Purpose, proposals, and pitfalls

The explicit ***purpose*** of this Recommended Practice is to propose a limited set of test waveforms that can be used for subjecting equipment to representative surge stresses as encountered in the low-voltage a.c. power environment.

This set is a ***proposal***, not a specification; it should be seen as a menu from which equipment manufacturers and users can select stress levels, as determined by the selected test waveform(s) and amplitude(s) best suited for their own application.

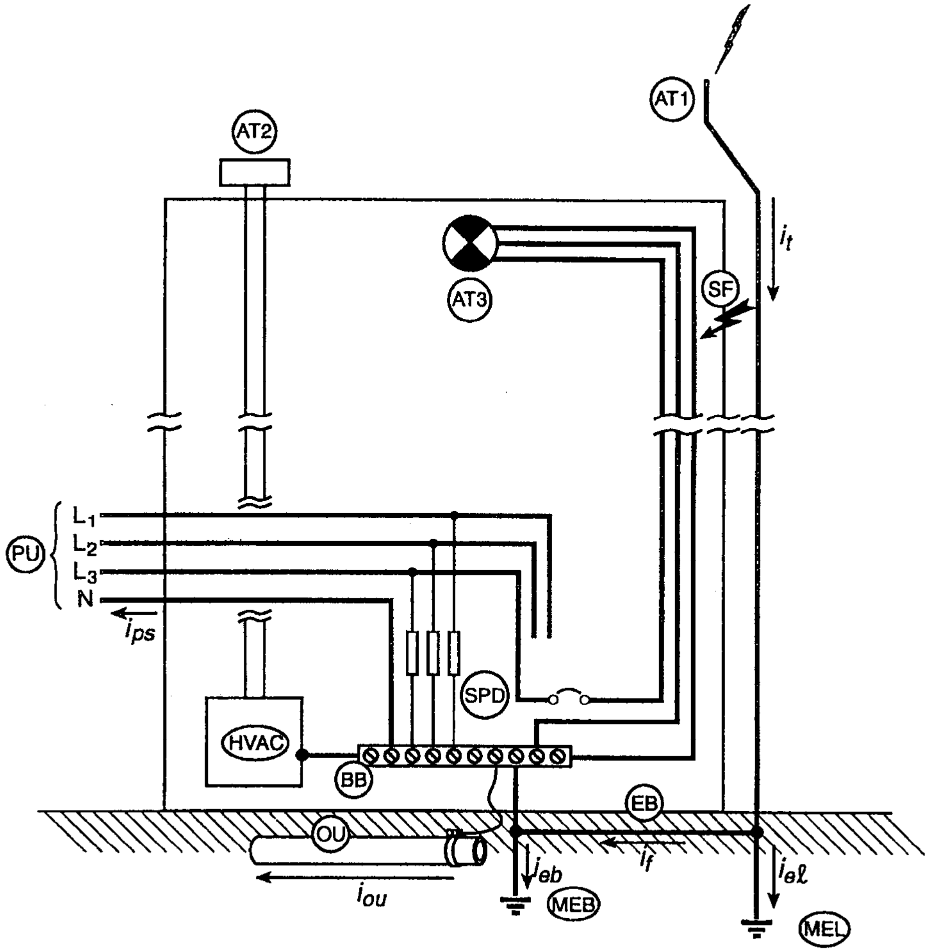
The common ***pitfall***, however, has been in the past that the purpose was misinterpreted and the proposals were turned into equipment specifications that were expected to be appropriate for all applications. Continuing efforts in the redaction of the successive versions of the document have been made, and appear to have reduced but still not yet completely eradicated such misinterpretations.

The menu aspect of this Recommended Practice will be emphasized by suggesting two types of test waveforms. First, a set of two "Standard Waveforms" recommended for general applications; then a set of "Additional Waveforms" recommended for special applications where they appear appropriate.

5.2 Standard Waveforms

The original 1980 version proposed two representative waveforms, and these have not changed since. The first waveform, labeled "0,5 μs — 100 kHz Ring Wave" was constructed on the basis of the then novel recognition that the traditional test waveforms used in high-voltage laboratories might not be a good representation of the environment in low-voltage a.c. power circuits. Even the limited field recordings available at that time were showing oscillatory, high-frequency waveforms rather than the textbook unidirectional impulses.

The second waveform, actually a combination of two stress types, was proposed for subjecting equipment to a voltage stress (1,2/50 μs) when the equipment would present a high impedance, or a current stress (8/20 μs) when the equipment would present a low impedance. This choice was influenced by the wish of not denying the long experience gained with those waveforms. In contrast to the then prevalent test methods where the current and voltage impulses were two separate tests, this second waveform would be applied by a generator having the inherent capability of delivering a voltage ***or*** a current stress according to the impedance of the equipment under test. This new type of generator and waveform became known as "Combination Wave."



AT1	Intended air terminal of "Lightning Protection System."
AT2	Unintended, but likely air terminal (Ventilation, air conditioning...)
AT3	Unintended, but possible air terminal if no others available.
SF	Side flash from down-conductor in the absence of bonding.
BB	Facility bonding bar.
EB	Earthing bonding.
MEB	Made earth electrode for building.
MEL	Lightning earthing electrode.
HVAC	Heating, ventilation, air conditioning equipment.
SPD	SPDs installed in the service entrance equipment.
PU	Power utility incoming connection.
OU	Other utilities (communications, water...)
i_t	Total lightning current.
i_f	Portion of lightning current into facility wiring.
$i_{e\ell}$	Portion of lightning current into lightning earthing electrode.
i_{eb}	Portion of lightning current into building made electrode.
i_{ps}	Portion of lightning current exit via electric power utility.
i_{ou}	Portion of lightning current exit via other utilities.

Figure 2 — Example of possible multiple paths for dispersion of the lightning current

5.3 Additional Waveforms

During the process of updating the 1980 vintage of the C62.41 Guide into the 1991 version, several waveforms were considered by the working group. The final proposal was to recommend considering a fast transient, adopted from the IEC 801-4 (now IEC 61000-4-4, called EFT for "Electrical Fast Transient"), a 10/1000 μs Long Wave, and a 5 kHz Ring Wave. These waveforms were designated as "Additional Waveforms" to emphasize that a test program should not be overburdened by unnecessary tests when there was no compelling reason to include one or more of these additional waveforms in the test regimen.

In the updating process for the Trilogy, the EFT and the Long Wave have been kept as Additional Waveforms. In the 1991 version, the 5 kHz waveform was intended to emulate capacitor switching surges. In the laboratory, a conventional type of energy-storage surge generator could produce that waveform superimposed to the power-frequency voltage. However, it has been abandoned as more data became available on the occurrence of capacitor switching surges, indicating that lower frequencies, below 1 kHz, were more typical. Instead, the recommendation is offered that specific studies be performed for installations where large capacitor banks are being switched frequently.

6. RECOMMENDED PRACTICE ON TESTING

One of the outcomes of the Recommended Practice on Surge Characterization is a set of tables indicating what types of surge test waveforms are recommended for specific combinations of conductors at the power port of equipment to be tested (phase, neutral, ground). To illustrate the process, Table 1 presents a summary of these recommendations for surge testing the a.c. power ports of equipment (including surge protective devices, of course).

Now turning to the recommendations on actually performing the recommended tests, in the 1980s and the early 1990s, guidance on surge testing was offered in the format of an IEEE Guide. In the Trilogy, with the experience accumulated in the use of the C62.45 Guide, augmented by some anecdotal examples of observed questionable surge testing procedures, the decision was made to elevate the C62.45 Guide to the more compelling visibility and status of a Recommended Practice.

This enhanced version also will address issues raised by the shift from analog to digital instruments and the resulting effects of aliasing, insufficient resolution, and transducer saturation. Precautions for avoiding artifacts will also be included in the recommendations.

7. SCHEDULE AND RELATIONS WITH OTHER STANDARDS

Efforts are being made to effect liaisons with the IEC Technical Committees TC37 and TC81, as well as with other parties involved in lightning studies. The effort has been difficult because the liaisons were not optimized and the work was sometimes conducted by different groups without sharing relevant information. It is one of the aims of this paper to lower these barriers by presenting the subject within the community of the ICLP participants.

The IEEE working group is hoping that the Trilogy will have matured through the summer of 2000, in particular the consensus on how to turn the agreed-upon Scenario II into one set of recommended test waveforms that represent the environment.

At the present time, IEC Publication 61643-1 [9] has been released, but it only specifies the types of tests, without reference to the location and environment in which the SPDs are to be installed.

Table 1
Summary of recommended types of surge tests

<table>
<tr><th colspan="6">Scenario I
(Surges impinging upon the structure from outside, and generated within)</th><th colspan="2">Scenario II
(Direct lightning flash)</th></tr>
<tr><th>Location Category</th><th>100 kHz Ring Wave *</th><th>Combination Wave *</th><th>EFT Burst 5/50 ns †</th><th>10/1000 μs Long Wave †</th><th>Capacitor Switching ¶</th><th>Inductive Coupling</th><th>Resistive Coupling §</th></tr>
<tr><td>A</td><td>Standard</td><td>None</td><td>Additional</td><td>Additional</td><td>Additional</td><td rowspan="3">Use the Category B Ring Wave</td><td rowspan="3">Case by case assessment</td></tr>
<tr><td>B</td><td>Standard</td><td>Standard</td><td>Additional</td><td>Additional</td><td>Additional</td></tr>
<tr><td>C</td><td>None</td><td>Standard</td><td>None</td><td>Additional</td><td>Additional</td></tr>
</table>

* Refer to 5.2 for details on the standard waveforms.
† Refer to 5.3 for details on the additional waveforms.
¶ On a case-by-case basis.
§ Pending development of consensus.

8. SUMMARY

The update of the two original documents IEEE Std C62.41 and IEEE Std C62.45, into a Trilogy will bring the following improvements to these two previous documents, notwithstanding the fact that they served well in the period of 1980 to 1999 (IEEE has filled over a thousand requests for C62.41 since its first publication):

The new structure will provide readers with a more direct route to fulfill their particular needs:

1. A basic guide providing comprehensive data base and the rationale for the simplification leading to the recommended standard and additional test waveforms;
2. A relatively terse description of the recommended test waveforms, uncluttered by the data base;
3. A straightforward and well-connected Recommended Practice on surge testing methods.

The most significant changes in the Trilogy, compared to the earlier versions of C62.41-1991 and C62.45-1992, are the following:

- Separation of the data base that was appended to C62.41 in the earlier versions, when enhancing acceptance and credibility of the proposals were deemed important elements. A Guide provides a comprehensive data base, a Recommended Practice provides the standard and additional test waveforms.
- Introduction of a Scenario II for the special case of a direct lightning flash to the building. Such a scenario implies higher stress levels for those surge-protective devices installed at the service entrance, compared with the stress levels suggested for usual applications.
- Introduction of the concept of transition overlaps that act as interfaces between Location Categories, rather than the boundaries that previously separated these categories;
- Removal of the earlier attempt to provide across-the-board waveforms for the case of capacitor switching, but instead make recommendation to perform case-by-case studies.

9. ACKNOWLEDGMENTS

The development of the IEEE C62 Trilogy update has been made possible only with the technical contributions and moral support of my colleagues, too numerous to list them all, from several standards-writing groups, but who nevertheless deserve recognition for their voluntary work.

Another beneficial factor that needs recognition is the growing trend toward harmonization among standards-writing organizations, in spite of their initial divergent positions.

10. REFERENCES

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